RELATIVE INTENSITIES OF GAMMA RAYS IN IR 192 AND IR 194 DECAY

by

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INTRODUCTION

The purpose of this work was to examine the decay of the two radioactive nuclei, Ir 192 and Ir 194, using a lithium-drifted germanium detector with the objectives being: to discover unreported gamma rays, to measure relative intensities of gamma ray transitions, and to verify previously reported gamma rays following the decay of these nuclei.

These nuclei have been studied extensively in the past and relative intensities of gamma rays determined using NaI scintillation detectors (1), magnetic focusing beta ray spectrometers (2, 3,4,5,6,7,8,), and curved crystal diffraction spectrometers (9). However; with the exception of Williams' work (10), which was primarily concerned with determining the beta ray intensities feeding the levels in Ir 194, they have not been studied using a solid state detector.

A Ge(Li) detector has at least one order of magnitude better energy resolution, defined as the full width at half maximum (FWHM), than does a NaI detector although its efficiency for gamma detection is lower. Photo-peaks unresolved in NaI detectors are often resolved in Ge(Li) detectors and subsequent intensity calculations should be more accurate. A Ge(Li) detection system does not have the high, energy resolution capability of the other two mentioned methods of detection and consequently is not as suitable for precise determination of gamma ray energies; however, there are three experimental advantages to be gained by using Ge(Li) detection. First, in accumulating data using either a

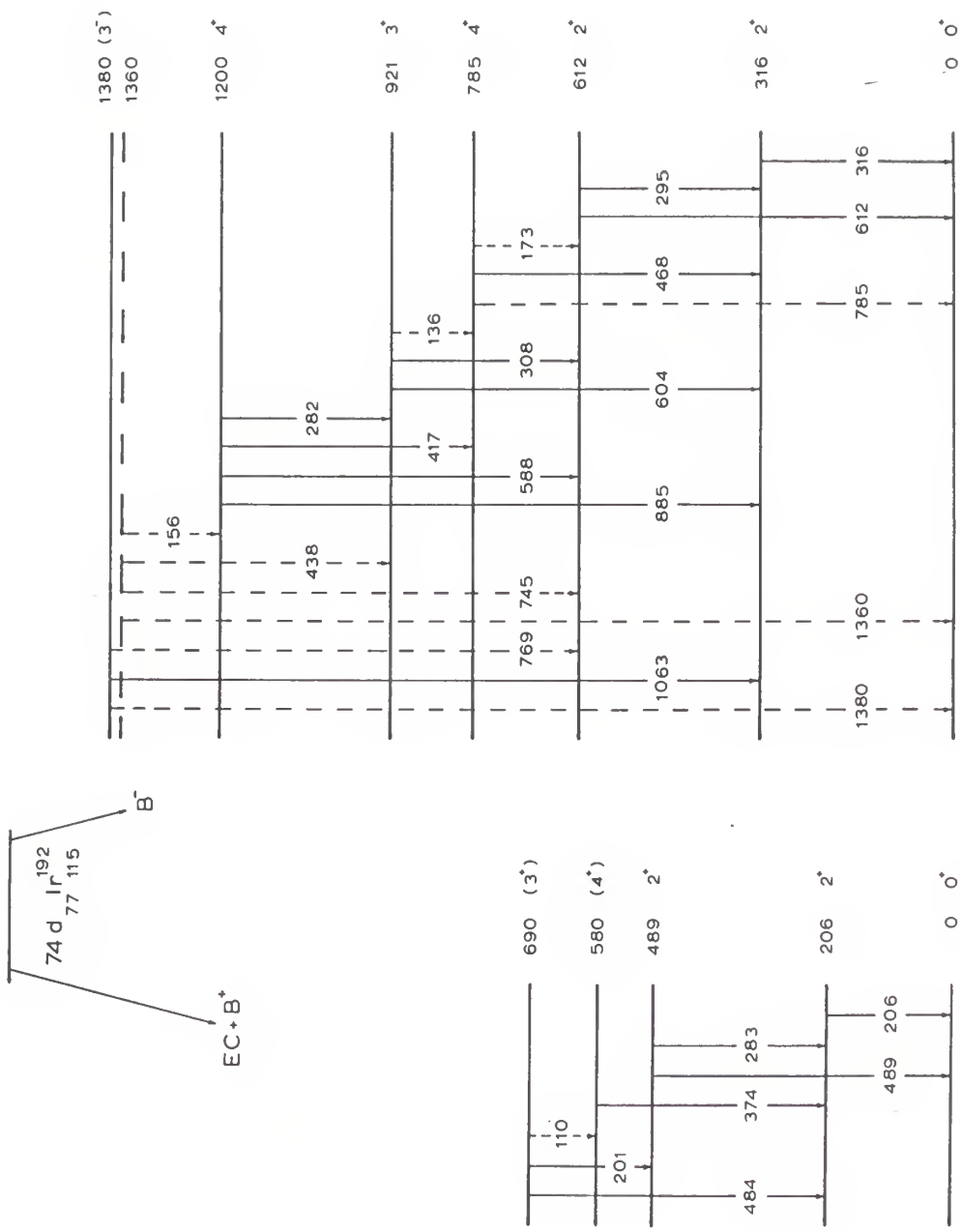
beta ray or crystal diffraction spectrometer, data points must be taken one at a time over the energy range of interest whereas in Ge(Li) detection the whole range is viewed simultaneously. Thus the error in the counts due to decaying source is completely eliminated. Second, both spectrometer methods employ an intermediate interaction between the emitting source and the detecting apparatus. Ge(Li) detection is a direct process and less experimental error should be present due to a smaller number of geometrical factors. Third, both spectrometer detection systems require very strong sources, approximately 1 Curie, while Ge(Li) detection systems require approximately 10^{-3} Curie source strength.

Present knowledge concerning the energy levels and transitions between levels is displayed in the decay schemes, Plate I for Ir 192 and Plate II for Ir 194. The Ir 192 decay scheme is that appearing in Nuclear Data Sheets (11). Dotted lines, indicating transitions between levels, correspond to transitions not observed in this work. A level is dotted if all transitions from that level were unobserved. The 589 keV gamma ray was previously unreported in the decay of Ir 194.

EXPLANATION OF PLATE I

Nuclear level structure of $_{78}Pt^{192}_{114}$ and $_{76}Os^{192}_{116}$.

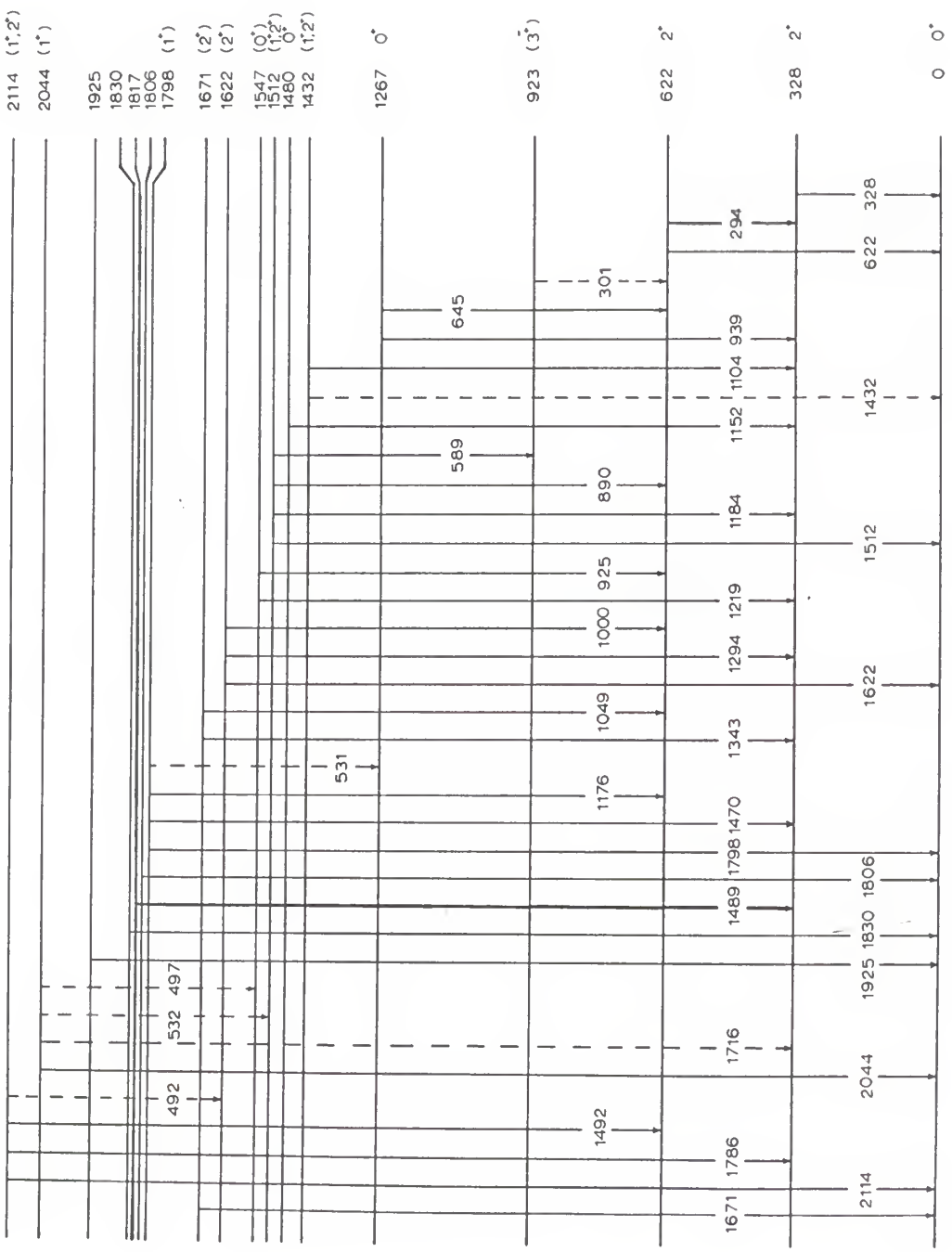
PLATE I


74 d
$Ir^{192}_{77\ 115}$
β^-
EC + β^+
1380 (3⁻)
1360
1200 4⁺
921 3⁺
785 4⁺
612 2⁺
316 2⁺
0 0⁺
156
438
282
417
136
588
308
173
769
745
885
604
468
295
1063
1380
1360
785
612
316
$Pt^{192}_{78\ 114}$
690 (3⁺)
580 (4⁺)
489 2⁺
206 2⁺
0 0⁺
110
201
484
374
283
489
206
$Os^{192}_{76\ 116}$

EXPLANATION OF PLATE II

Nuclear level structure of $_{78}Pt^{194}_{116}$.

PLATE II


2114 (1,2+)
2044 (1+)
1925
1830
1817
1806
1798 (1+)
1671 (2+)
1622 (2+)
1547 (0+)
1512 (1,2+)
1480 0+
1432 (1,2+)
1267 0+
923 (3-)
622 2+
328 2+
0 0+
645
589
531
497
532
492
1492
1786
1671
1716
2114
2044
1925
1830
1806
1489
1798
1470
1343
1176
1049
1000
925
890
301
1622
1294
1219
1184
1152
1104
939
1512
1432
294
622
328
194
78Pt116

EXPERIMENTAL PROCEDURE

The experimental procedure is divided into three parts, the experimental set-up, the source preparation, and the accumulation of data.

Experimental Set-up

Plate III is a block diagram exhibiting the geometry, physical properties of the detection system, and the electronics employed in the experiment.

The preamplifier used was the Tennelec Model TC 100 (Ser. No. 44), a charge-sensitive preamplifier specially designed for use with cooled semiconductor detectors. It has a charge sensitivity of 0.21 uv per ion pair or equivalently 74 mv per 1 meV loss in a Ge(Li) detector, according to specifications.

The main amplifier used was the Tennelec Model TC 200 (Ser. No. 77), having a total gain of from 4 to 2048 with a differential nonlinearity of 0.1% when loaded, according to specifications.

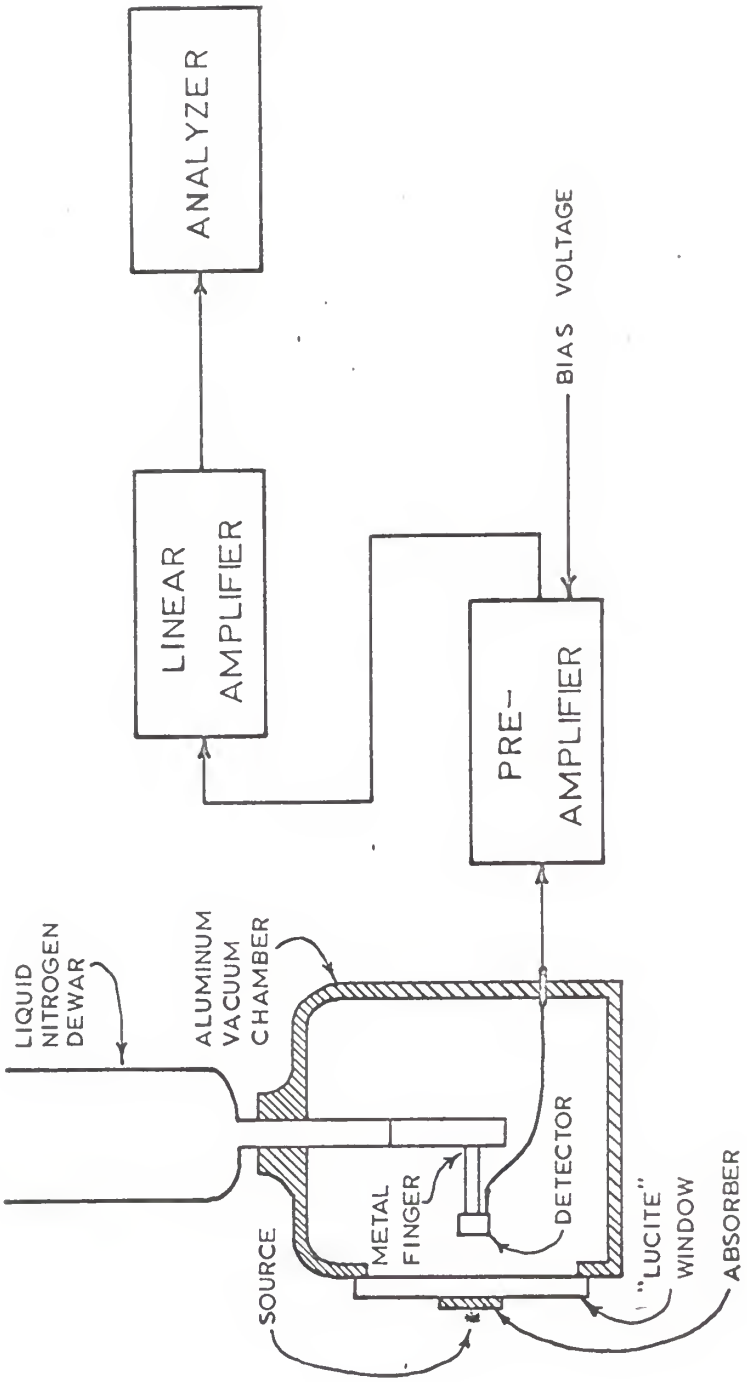
Bias voltage was supplied from the TC 200.

The analyzer used was the Technical Measurement Corporation (TMC) 4096 multiparameter pulse analyzer system. With the Model 213 pulse height logic unit, the system has a differential linearity of 2% of full scale, a time stability of less than 0.5% of full scale channel drift per 30 degrees Centigrade, and up to 5×10^4 counts per second with no change in drift or linearity, according to specifications.

EXPLANATION OF PLATE III

Block diagram showing the apparatus and electronics used in accumulating singles spectra.

PLATE III


ANALYZER
LINEAR AMPLIFIER
PRE-AMPLIFIER
BIAS VOLTAGE
LIQUID NITROGEN DEWAR
ALUMINUM VACUUM CHAMBER
SOURCE
METAL FINGER
DETECTOR
"LUCITE" WINDOW
ABSORBER

The detector was a lithium-drifted germanium detector manufactured by Solid State Radiations, Incorporated. It had an active area of 100 mm^2, a depletion depth of 4.2 mm, a 0.3 mm Ge window, and a 0.384 mm Al case. The detector was cooled to liquid nitrogen temperature by fastening the detector to a copper mounting that was in turn connected to a kovar metal finger of a vessel filled with liquid nitrogen. The chamber was then evacuated with a vacuum pump.

Ir 194 decay possessed low intensity, high energy gamma rays and high intensity, low energy gamma rays. To prevent swamping the detector with these low energy radiations, an absorber pack was used for the study of Ir 194 decay. Approximately 3/4 of the gamma rays at 300 keV and 1/4 of the gamma rays at 1 meV were attenuated in the absorber. The absorber consisted of 3.6 mm of Pb, 2.4 mm of Cd, 1.4 mm of Cu, and 1.3 mm of Al. The aluminum chamber had a 6.1 mm lucite window. The ordering of the absorbers was Pb, Cd, Cu, and Al with Pb being next to the source. This ordering and these thicknesses shielded the detector from fluorescent radiation produced in the photoelectric absorbtion process.

Source Preparation

The Ir 194 source was prepared on location by irradiating stable iridium metal in the Triga Mark II reactor located on the Kansas State University campus. Approximately 3 mg of iridium metal, whose natural composition is 38.5% Ir 191 and 61.5% Ir 193 was wrapped in aluminum foil, sealed in a polyethelene sample

container, and irradiated for 30 minutes in a slow neutron flux of 4×10^{12} n/(cm^2 sec). This produced Ir 192 and Ir 194 with respective activities of 3.48×10^{-5} and 2.22×10^{-3} Curies or with a ratio of Ir 194 to Ir 192 of 64:1. The iridium powder was then sealed between the adhesive sides of "scotch" tape. The diameter of the source was approximately 4-5 mm.

Ir 192 in chemical form Na_2IrCl_6 and with purity greater than 98% was purchased from the Oak Ridge National Laboratory. The material was in solution in HCl acid. A few drops of solution was placed on the adhesive side of "scotch" tape and allowed to dry. When the source was sealed with another piece of tape, it was about 6-10 mm in diameter.

An alternate source for the study of Ir 192 ($T_{\frac{1}{2}}$ = 70d) was produced by allowing the Ir 194 ($T_{\frac{1}{2}}$ = 19hr) to decay, leaving only the longer lived iridium activity. However; for this work, the calculations were made from data taken using the source material purchased from Oak Ridge.

Accumulation of Data

Data were accumulated for both Ir 192 and Ir 194 using the previously mentioned electronics with the analyzer in the singles mode of operation. The absorber pack was used for Ir 194 while the source was placed on the lucite window of the vacuum chamber for the Ir 192 experiment. Plates IV and V exhibit typical singles spectra taken with amplifier gain positions set to view the low and high energy portions of each spectrum.

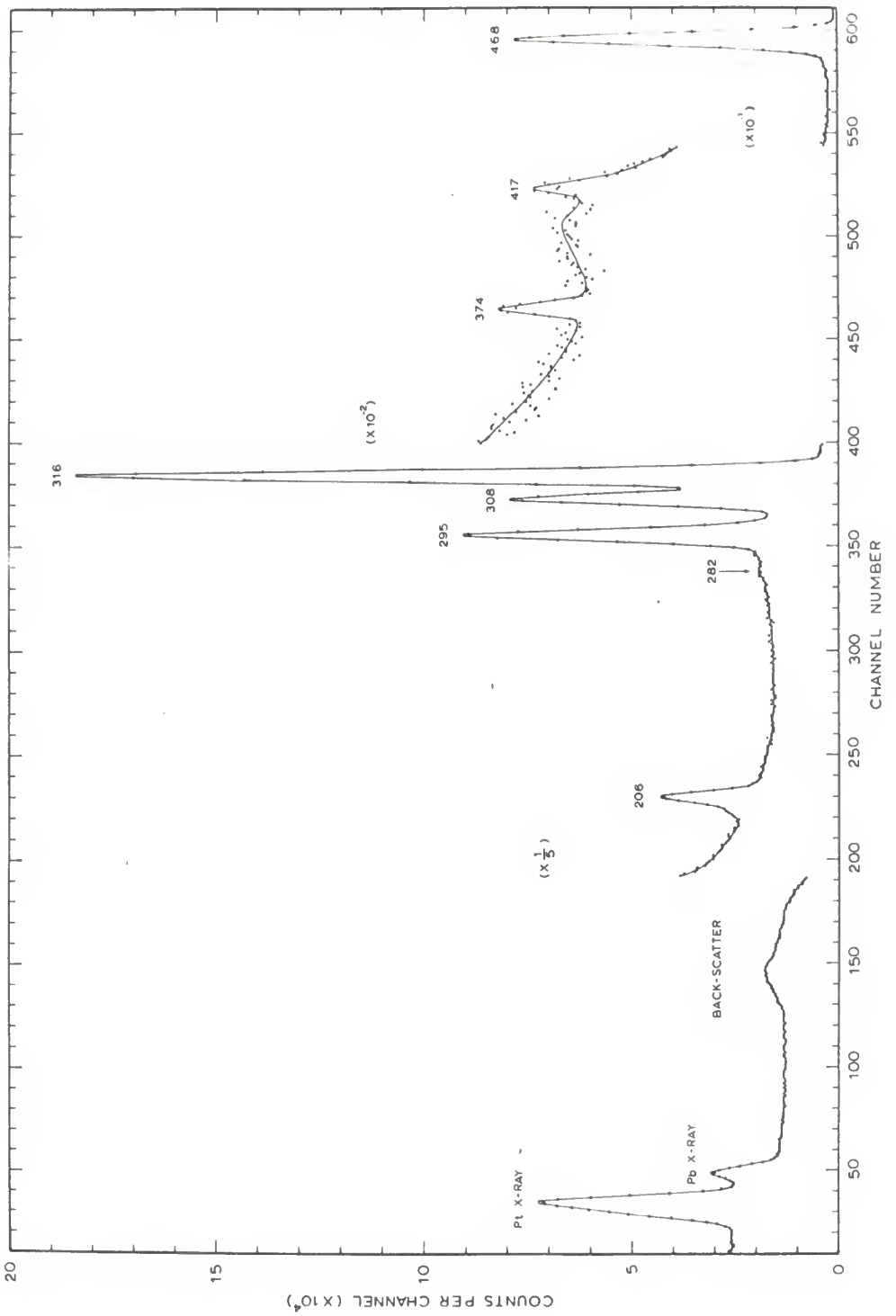
Data were accumulated for Ir 194 for 5 days, starting about 20 minutes after the source material was taken from the reactor so that half-life determinations could be made. No attempt was made to accumulate data for half-life determinations on Ir 192.

A background was accumulated without the source for each amplifier gain setting for the same period of time as the data run so that the data could be corrected for background radiations.

EXPLANATION OF PLATE IV (a)

A 30 minute singles spectrum with background subtracted showing the low energy gamma rays in Pt^{192} and Os^{192}. The FWHM of the 295 keV gamma ray peak was 4.7 keV.

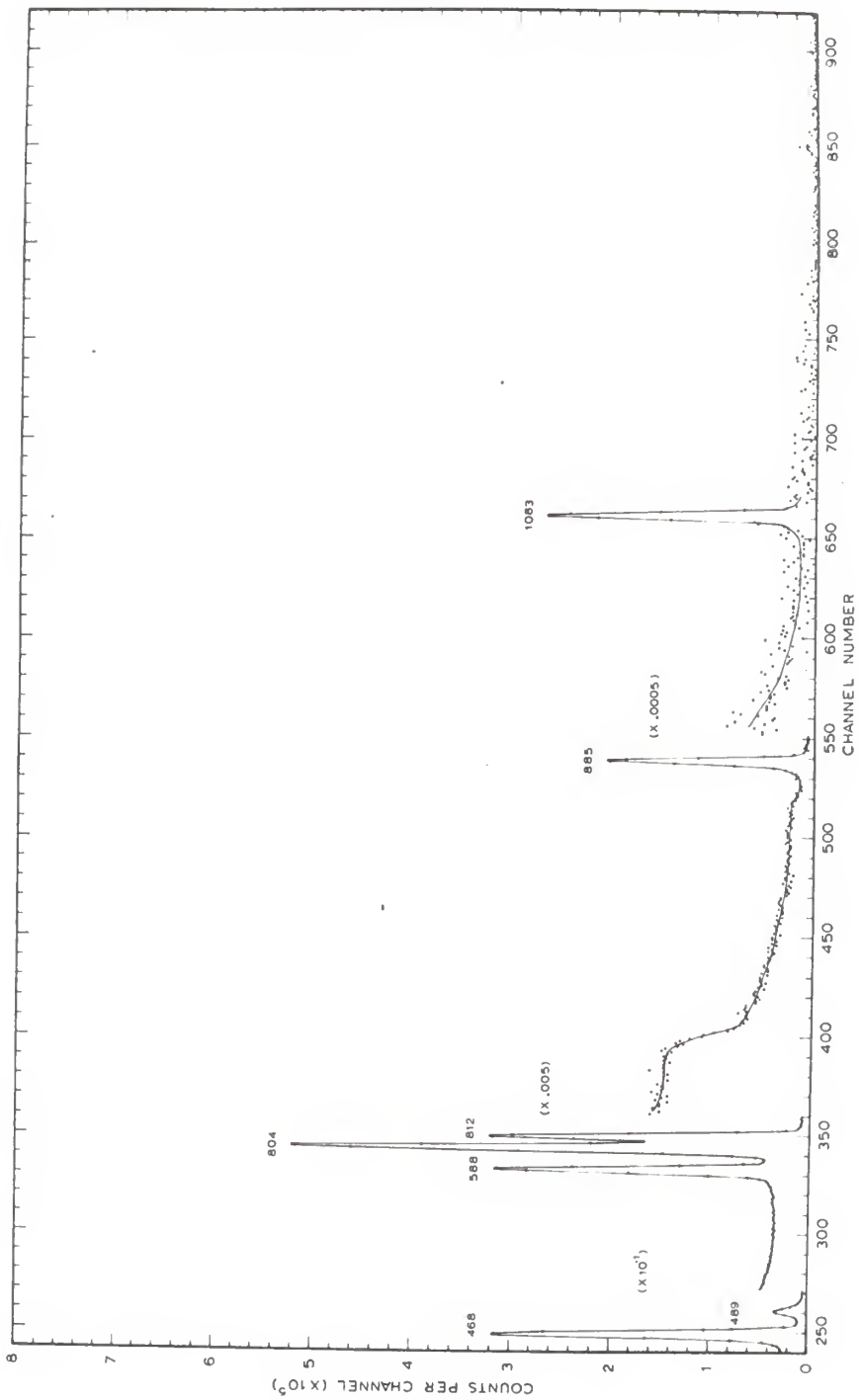
PLATE IV (a)


COUNTS PER CHANNEL (X 10⁴)
CHANNEL NUMBER
Pt X-RAY
Pb X-RAY
BACK-SCATTER
206
282
295
308
316
374
417
468
(X 1/5)
(X10⁻²)
(X10⁻¹)

EXPLANATION OF PLATE IV (b)

A 400 minute singles spectrum with background subtracted showing the high energy gamma rays in Pt^{192} and Os^{192}. The FWHM of the 885 keV gamma ray peak was 5.0 keV.

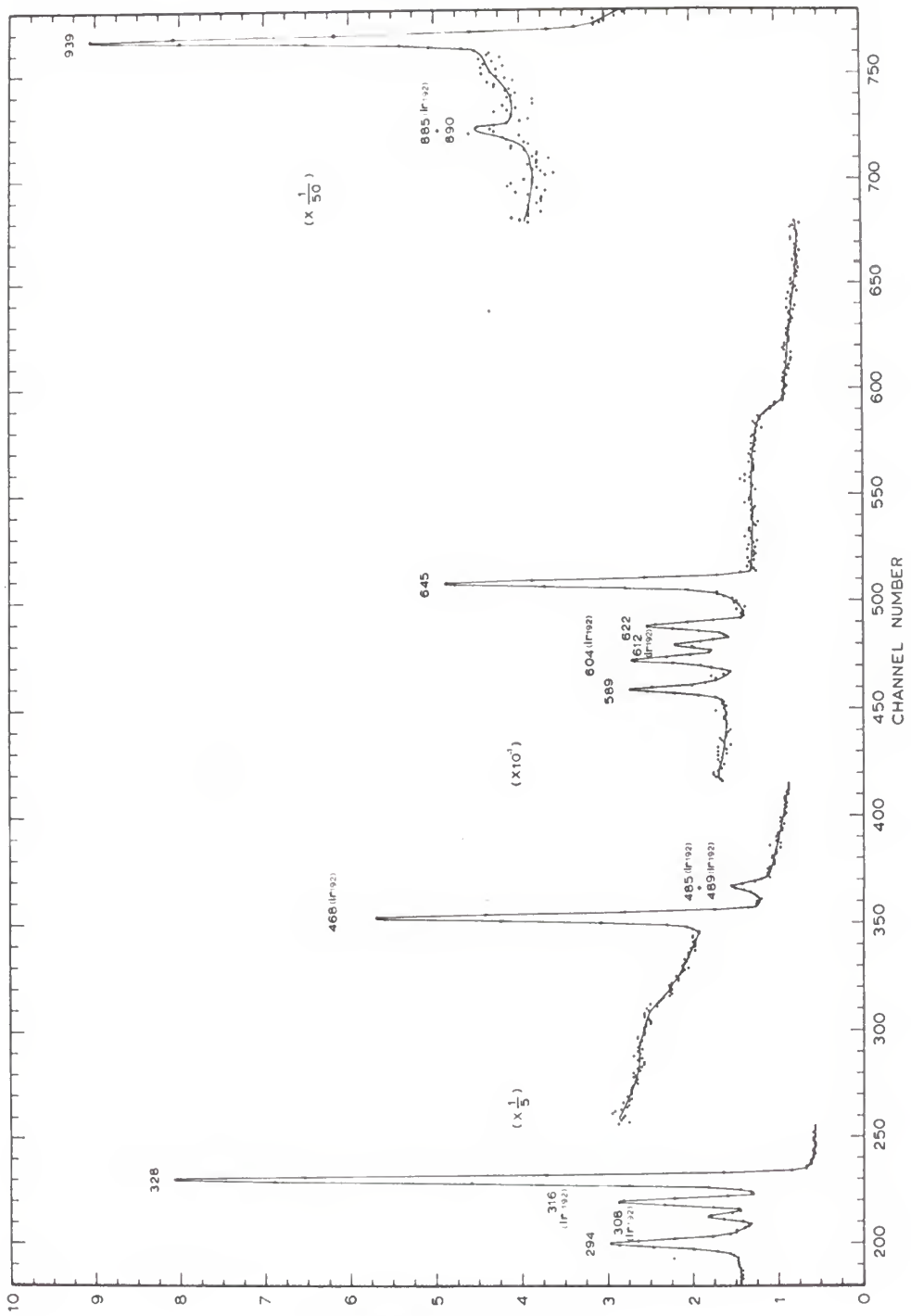
PLATE IV (b)


COUNTS PER CHANNEL (X 10^5)
CHANNEL NUMBER
468
489
804
812
588
885
1083
(X 10^-1)
(X .005)
(X .0005)

EXPLANATION OF PLATE V (a)

A 20 minute singles spectrum with background subtracted showing the low energy gamma rays in Pt^{194}. The FWHM of the 645 keV gamma ray peak was 4.8 keV.

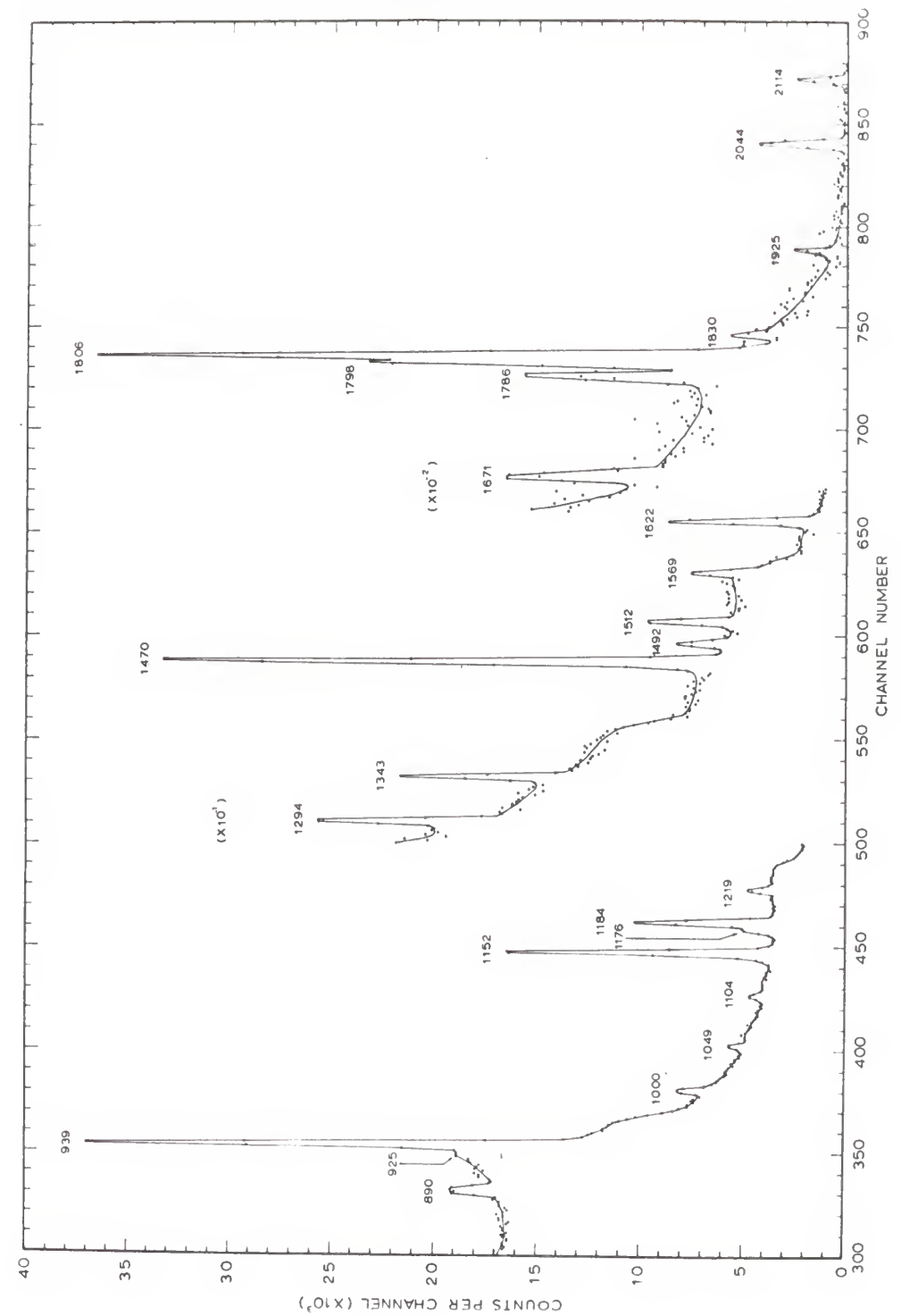
PLATE V (a)


939
885 (Ir-192)
890
(x 1/50)
645
604 (Ir-192)
622
612 (Ir-192)
589
(x10⁻¹)
468 (Ir-192)
485 (Ir-192)
489 (Ir-192)
(x 1/5)
328
316 (Ir-192)
308 (Ir-192)
294
COUNTS PER CHANNEL (x10⁴)
CHANNEL NUMBER

EXPLANATION OF PLATE V (b)

An 800 minute singles spectrum with background subtracted showing the high energy gamma rays in Pt^{194}. The FWHM of the 1470 keV gamma ray peak was 6.9 keV.

PLATE V (b)


COUNTS PER CHANNEL (X10³)
CHANNEL NUMBER
939
925
890
1000
1049
1104
1152
1184
1176
1219
1470
1294
1343
(X10¹)
1512
1492
1569
1622
1671
(X10⁻²)
1798
1786
1806
1830
1925
2044
2114

DETERMINATION OF RELATIVE INTENSITIES

To determine relative intensities, a singles spectrum is used. If every gamma ray emitted from the source was detected in the photo-peak, then the relative intensities would be proportional to the areas of the peaks in the spectrum. Since this is not the case, the areas in the spectrum must be corrected for peak-to-total value and efficiency of detection of a gamma ray.

Peak-to-Total Ratio

The peak-to-total ratio is defined as the fraction of the interactions in the detector which occur in the photo-peak. There are three primary ways a gamma ray can interact in the detector, leaving all or part of its energy.

The gamma ray can interact through the photoelectric effect giving rise to the photo-peaks in the spectrum. In the photo-electric process the gamma ray gives all its energy to one of the bound germanium electrons. The difference between the gamma ray energy and the binding energy of the electron appears as kinetic energy of the electron. The energetic electron ionizes other germanium atoms until all the gamma ray energy is dissipated in the detector in the formation of ion pairs.

If the gamma rays energy is greater than twice the rest mass of an electron (1.02 meV), the interaction can take place by a process known as pair production. Pair production takes place near a nucleus with the result that the gamma ray disappears and

an electron, positron pair is produced. The difference between the gamma ray energy and twice the rest mass energy of an electron appears as kinetic energy of the electron and positron. The positron eventually comes to rest in the detector and annihilation occurs, freeing 1.02 meV of energy in the form of two 511 keV photons. Either or both of these photons can lose all or part of their energy in the detector with the result that the energy detected varies continuously from E_γ - 1.02 meV to E_γ.

The third principle interaction is by Compton scattering of the gamma ray. In this process, the gamma ray is scattered inelastically by an essentially free electron. The equation for the energy of the scattered gamma ray is:

$$E'_\gamma = \frac{E_\gamma}{1 + \frac{E_\gamma (1-\cos \theta)}{mc^2}}$$

E'_γ is the new photon energy, E_γ is the gamma ray energy, mc^2 = 511 keV, and θ is the angle between the two photons. The recoil electron energy is $E_\gamma - E'_\gamma$. There is a maximum energy loss in the detector corresponding to θ = 180 degrees, assuming the scattered photon escapes the detector.

These three types of interaction depend upon the atomic number of the absorbing material and vary continuously with energy. In germanium, the photoelectric effect dominates from about 0-200 keV, the Compton effect from 0.200-8 meV, and pair production from 8- meV (12).

The peak-to-total ratio is the ratio of the interactions taking place by the photoelectric effect to all interactions which

dissipate energy in the detector. Because of the complex modes of interaction and the fact that geometrical properties of the detector influence these processes, there does not exist theoretical peak-to-total ratios; therefore, they must be determined experimentally.

Efficiency of Detection

The efficiency at energy E, e(E), is defined to be the ratio of the number of gamma rays detected to the number of gamma rays entering the detector. The efficiency for a cylindrical detector of radius r, thickness t, and a total attenuation coefficient for the detector material u(E), assuming a point source located a distance h above the detector on the symmetry axis is given by the following expression (13):

$$e(E) = \frac{1}{1-\cos\Theta}\left\{\int_0^{\Phi}\left[1-e^{-\frac{\mu(E)t}{\cos\theta}}\right]\sin\theta\,d\theta + \int_{\Phi}^{\Theta}\left[1-e^{-\mu(E)\left(\frac{r}{\sin\theta}-\frac{h}{\cos\theta}\right)}\right]\sin\theta\,d\theta\right\}$$

where $\Theta = \tan^{-1} r/h$ and $\Phi = \tan^{-1} r/(h + t)$

If, in addition, absorbing material is between the source and detector, the efficiency is given by $e'(E) = e(E) \times e^{-\sum u_i(E)\,t_i}$ where $u_i(E)$ is the total attenuation coefficient and t_i is the thickness for the i^{th} absorber.

A computer program was written, employing Simpson's rule for the numerical integration, to provide efficiency correction factors.

Calculations

Raw areas were obtained from the singles spectra of Ir 192 and Ir 194 by summing the counts per channel over the peaks area and then subtracting an estimated Compton background. In the case of Ir 194 an additional correction was made for the 294, 589, and 890 keV gamma rays because those peaks contained contributions from the 295, 588, and 885 keV gamma rays in Ir 192. For the 294 keV gamma ray, a singles spectrum of Ir 192 was used to determine the areal ratio of the 295 keV peak to the composite peak of the 308, 316 keV gamma rays. When the area of the composite peak of the 308, 316 keV gamma rays appearing in the Ir 194 spectrum was multiplied by this ratio and this value subtracted from the area of the 294 keV peak, the result was the correct value for the 294 keV gamma ray in Ir 194. The other two peaks were treated in a similar manner.

The raw areas were adjusted to their final values by multiplying them by their appropriate correction factors for detection efficiency and peak-to-total ratio. The correction factors are reciprocals of the ratios. The peak-to-total values were determined experimentally (14) for the detector used in this work. For the efficiency program, cross-sections were taken from a report issued by the Atomic Energy Commission (15). For absorbers, the total absorbtion coefficient was used while for the detector only those coefficients were selected which corresponded to processes which deposited energy in the detector. The other parameters for efficiency were r = 0.564 cm, t = 0.420 cm, and h = 5.098 cm, 4.228 cm (no absorbers). Tables 1 and 2 display the uncorrected data, correction factors, and corrected data for Ir 192 and Ir 194 respectively.

Table 1. Data Used to Determine Relative Intensities of Gamma Rays in Pt^{192} and Os^{192}.

Gamma Ray Energy (keV)	Uncorrected Areas	Efficiency Correction Factor	Peak-to-Total Correction Factor	Corrected Areas
201 206	403,294 (1.48%)	4.30	3.03	5,254,500
282 283	13,809 (5.49%)	5.35	4.93	364,210
295	1,155,941 (0.92%)	5.57	5.49	35,348,000
308	1,133,119 (0.88%)	5.73	6.06	39,346,000
316	3,003,299 (0.75%)	5.80	6.37	110,960,000
374	14,887 (2.28%)	6.38	8.70	826,320
417	14,001 (2.39%)	6.70	10.8	1,013,100
468	678,825 (0.13%)	7.09	13.3	64,011,000
484 489	45,782 (0.55%)	7.20	14.3	4,713,700
588	37,475 (0.58%)	7.83	20.2	5,927,300
604	64,586 (0.42%)	7.90	21.1	10,766,000
612	38,132 (0.56%)	7.98	21.3	6,481,400
885	1,075 (3.52%)	9.20	36.5	360,990
1063	131 (8.14%)	9.90	46.3	60,046

Table 2. Data Used to Determine Relative Intensities of Gamma Rays in Pt^{194}.

Gamma Ray Energy (keV)	Uncorrected Areas	Efficiency Correction Factor	Peak-to-Total Correction Factor	Corrected Areas
294	749,505 (2.61%)	45	5.41	182,470,000
328	3,167,368 (1.03%)	37	6.76	792,220,000
589	32,477 (5.08%)	16.9	20.0	10,977,000
622	45,551 (1.72%)	16.6	22.0	16,635,000
645	187,300 (0.35%)	16.5	23.0	71,080,000
890	4,592 (13.04%)	15.9	36.6	2,672,300
925	1,774 (29.72%)	15.9	38.8	1,094,400
939	43,243 (1.61%)	15.9	39.2	26,952,000
1000	4,820 (4.40%)	15.9	42.6	3,264,800
1049	1,799 (8.23%)	16.0	45.5	1,309,700
1104	2,057 (7.92%)	16.0	48.3	1,589,600
1152	39,433 (0.68%)	16.1	51.0	32,378,000
1176	4,539 (5.84%)	16.1	52.4	3,829,300
1184	18,047 (2.01%)	16.2	53.5	15,641,000
1219	2,973 (4.91%)	16.2	54.6	2,629,700
1294	2,379 (5.17%)	16.4	59.5	2,321,400
1343	1,809 (5.64%)	16.5	62.1	1,853,600
1470	8,483 (1.41%)	16.9	68.5	9,820,300
1489 1492	687 (9.49%)	16.9	69.4	805,750

Table 2 (cont.). Data Used to Determine Relative Intensities of Gamma Rays in Pt^{194}.

Gamma Ray Energy (keV)	Uncorrected Areas	Efficiency Correction Factor	Peak-to-Total Correction Factor	Corrected Areas
1512	1,295 (5.58%)	17.0	70.4	1,549,900
1569	567 (9.21%)	17.2	73.5	716,800
1622	2,039 (2.82%)	17.3	76.9	2,712,600
1671	359 (9.33%)	17.4	79.4	495,980
1786	262 (11.45%)	17.7	86.2	399,740
1798	293 (10.31%)	17.7	87.0	451,190
1806	1,033 (3.88%)	17.8	87.0	1,599,700
1830	66 (19.40%)	18.0	87.3	106,090
1925	54 (19.63%)	18.1	94.3	92,169
2044	141 (8.87%)	18.4	100	259,440
2114	68 (12.50%)	18.5	104	130,830

THE 589 KEV GAMMA RAY

The gamma rays in Ir 194 ($T_{\frac{1}{2}}$ = 19hr) were not checked individually with half-life calculations, however they were compared visually to the Ir 192 ($T_{\frac{1}{2}}$ = 70d) gamma rays also appearing in the Ir 194 spectra. When this was done it was observed that the 588 keV gamma ray peak, supposedly belonging only to the Ir 192 decay, appeared to decay with a half-life intermediate to the adjacent 604, 612 keV pair known to belong to the Ir 192 decay and the 622 keV gamma ray peak in the Ir 194 decay. Plate VI shows this combination of gamma rays for two widely separated times. The appearance of an intermediate half-life suggested that there was a gamma ray transition close to 588 keV in Ir 194 that was previously unreported since there was no visual broadening of the peak and the mixture of a 19 hour and 70 day half-life would produce an effective half-life between those values.

In order to determine whether there was a component of the 588 keV peak decaying with a 19 hour half-life, a previously described procedure was used to subtract the contribution to the peak due to the 588 keV gamma ray in Ir 192.

The data were plotted on semi-logarithmic graph paper, and a straight line was fitted by a computer program to the points by the method of least squares (16). For the equation $y = A_o + A_x$, it was assumed that there was no error variation in x (time) and the points were weighted, giving the weight of one to the point having the smallest percentage error. The significant equations are:

$$\omega_1 \sigma_{y_1}^2 = \omega_2 \sigma_{y_2}^2 = \cdots = \omega_n \sigma_{y_n}^2 = \sigma^2$$

$$A_0 = \frac{\sum_i \omega_i y_i \sum_j \omega_j x_j^2 - \sum_i \omega_i x_i \sum_j \omega_j x_j y_j}{\sum_i \omega_i \sum_j \omega_j x_j^2 - \left(\sum_i \omega_i x_i\right)^2} = \frac{\bar{y} \sum_i \omega_i x_i^2 - \bar{x} \sum_i \omega_i x_i y_i}{\sum_i \omega_i (x_i - \bar{x}_i)^2}$$

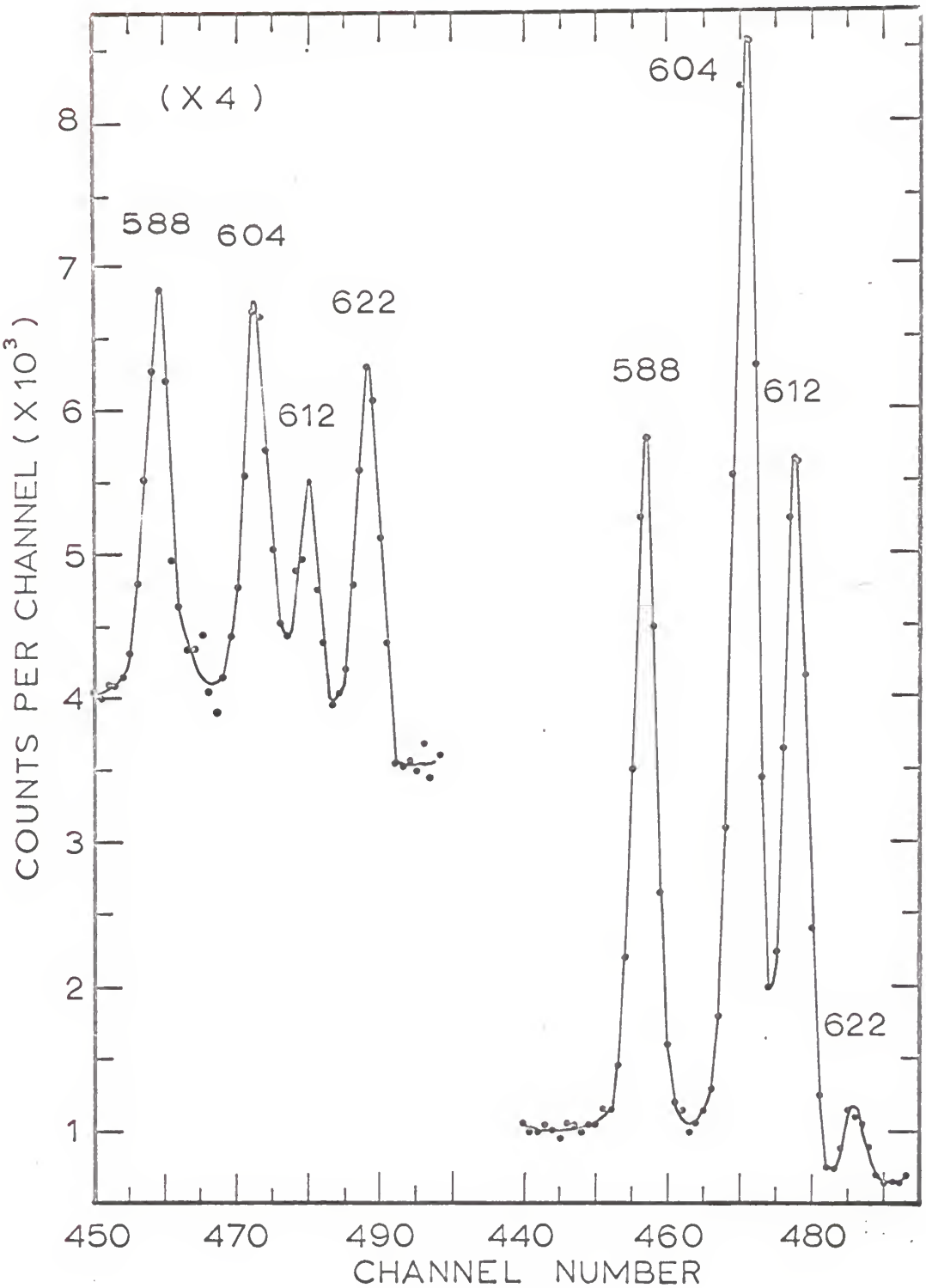
$$A_1 = \frac{\sum_i \omega_i \sum_j \omega_j x_j y_j - \sum_i \omega_i x_i \sum_j \omega_j y_j}{\sum_i \omega_i \sum_j \omega_j x_j^2 - \left(\sum_i \omega_i x_i\right)^2} = \frac{\sum_i \omega_i (x_i - \bar{x}_i)(y_i - \bar{y}_i)}{\sum_i \omega_i (x_i - \bar{x}_i)^2}$$

where σ_{y_i} is the percent error in the number of counts in the peak, σ^2 was chosen equal to the smallest percent error, and x = log N. Plate VII shows the fitted data with $T_{\frac{1}{2}} = 21.6 \pm 1.2$ h.

EXPLANATION OF PLATE VI

Comparison of the decay rate of a combination of gamma rays appearing in the decay of Ir 194. Both combinations were taken from singles spectra with the right-hand portion having been accumulated 74.5 hours after the left-hand portion. The left-hand side was accumulated for 20 minutes and the right-hand side for 120 minutes. Each has background subtracted.

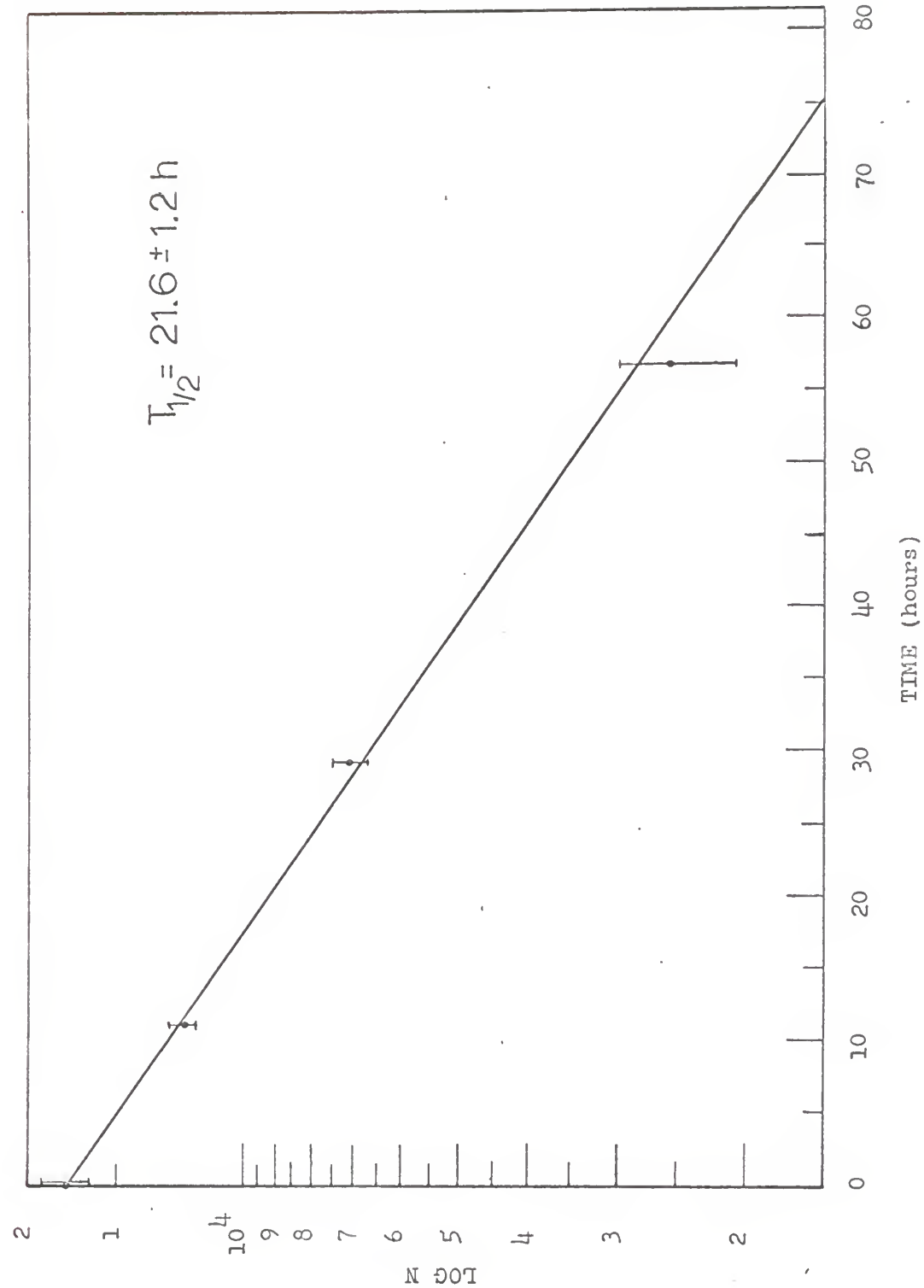
PLATE VI


(X 4)
588
604
622
612
604
588
612
622
COUNTS PER CHANNEL (X 10³)
CHANNEL NUMBER
1
2
3
4
5
6
7
8
450
470
490
440
460
480

EXPLANATION OF PLATE VII

The half-life of the 588 keV gamma ray peak in the Ir 194 spectra after correcting for the 588 keV gamma ray in the Ir 192 decay. The times have been adjusted so the first data point is at time t=0. N is the number of counts in the corrected peak.

PLATE VII


$T_{1/2}$ = 21.6 ± 1.2 h
LOG N
2
1
10^4
9
8
7
6
5
4
3
2
0
10
20
30
40
50
60
70
80
TIME (hours)

```
C
C     THIS PROGRAM FITS A STRAIGHT LINE TO FROM 3 TO 90 DATA POINTS BY
C          THE METHOD OF LEAST SQUARES
C
      DIMENSIONX(90),Y(90),W(90),WX(90),WXSQ(90),WY(90)
      DIMENSIONWXY(90),D(90),DSQ(90),DIFY(90),DIFX(90),DIFXY(90)
    1 FORMAT(I2,I4,A5)
    2 FORMAT(10F8.5)
    3 FORMAT(1H1,20X,48HLEAST SQUARES DETERMINATION OF THE HALF-LIFE OF
     1,I4,18H KEV GAMMA RAY OF ,A5,7H USING ,I2,7H POINTS///)
    4 FORMAT(43X,1HX,18X,1HY,13X,6HWEIGHT,10X,9HDEVIATION/)
    5 FORMAT(25X,4E19.8)
    6 FORMAT(///21X,8HAZERO = ,E13.7,9X,7HAONE = ,E13.7,9X,17HSTD. DEVIA
     1TION = ,E13.7)
    7 FORMAT(//21X,12HHALF-LIFE = ,E13.7,15H PLUS OR MINUS ,E13.7)
   14 READ(1,1)N,NERGY,SOTOPE
      IF(N.LT.2)STOP
      WRITE(3,3)NERGY,SOTOPE,N
      WRITE(3,4)
      READ(1,2)(X(I),I=1,N),(Y(J),J=1,N),(W(I),I=1,N)
      DO10I=1,N
      WY(I)=W(I)*Y(I)
      WX(I)=W(I)*X(I)
      WXSQ(I)=WX(I)*X(I)
   10 WXY(I)=WX(I)*Y(I)
      SUMWY=0.
      SUMWX=0.
      SMWXSQ=0.
      SUMWXY=0.
      SUMW=0.
      DO11I=1,N
      SUMWY=SUMWY+WY(I)
      SUMWX=SUMWX+WX(I)
      SMWXSQ=SMWXSQ+WXSQ(I)
      SUMWXY=SUMWXY+WXY(I)
   11 SUMW=SUMW+W(I)
      XBAR=SUMWX/SUMW
      YBAR=SUMWY/SUMW
      DO12I=1,N
      DIFY(I)=W(I)*((Y(I)-YBAR)*(Y(I)-YBAR))
      DIFXY(I)=W(I)*((X(I)-XBAR)*(Y(I)-YBAR))
   12 DIFX(I)=W(I)*((X(I)-XBAR)*(X(I)-XBAR))
      SMDY=0.
      SMDXY=0.
      SMDX=0.
      DO15I=1,N
      SMDY=SMDY+DIFY(I)
```

```
      SMDXY=SMDXY+DIFXY(I)
   15 SMDX=SMDX+DIFX(I)
      AZERO=((YBAR*SMDXSQ)-(XBAR*SUMWXY))/SMDX
      AONE=SMDXY/SMDX
      DO 16 I=1,N
   16 D(I)=Y(I)-(AZERO+(AONE*X(I)))
      SMDSQ=SMDY-((SMDXY*SMDXY)/SMDX)
      STDER=SQRT(SMDSQ/SUMW)
      HALFLF=(-.30103/AONE)
      ERRB=SQRT(SMDSQ/(SUMW*SMDX))
      ERHFLF=(.30103*ERRB)/(AONE*AONE)
      WRITE(3,5)(X(I),Y(I),W(I),D(I),I=1,N)
      WRITE(3,6)AZERO,AONE,STDER
      WRITE(3,7)HALFLF,ERHFLF
      GO TO 14
      END
```

Conclusion

Ir 192

Fourteen gamma rays in the decay of Ir 192 were completely or partially resolved and their intensities, normalized to the 316 keV gamma ray, measured. Since it was not possible to resolve the combinations of gamma rays (201 plus 206, 282 plus 283, and 484 plus 489 keV), it was assumed in each case that both gamma rays were present and the subsequent intensities were quoted for the pairs. Table 3 shows a comparison of the relative intensities obtained in this work to those obtained by other experimenters. Beta-ray spectrometers were used by all the other experimenters except Bergvall, whose values were obtained using a curved crystal diffraction spectrometer. The error quoted for the intensity values of this work is due entirely to the statistical fluctuation of the radioactive decay process.

The absence of previously reported gamma rays, shown dotted in the Ir 192 decay scheme, makes these transitions questionable. Since none of the transitions from the 1360 keV level in Pt^{192} were observed, the existence of this level is also uncertain.

Spectra taken with the Ir 194 source, after allowing the Ir 194 activity to disappear, produced the same gamma rays in Ir 192 decay as the source purchased from Oak Ridge. Relative intensities of the gamma rays above 283 keV agreed to within 10% to those found in the source obtained from Oak Ridge.

Ir 194

Thirty gamma rays in the decay of Ir 194 were completely or partially resolved and their intensities, normalized to the 1152 keV gamma ray, measured. It was not possible to resolve the 1489 and 1492 keV gamma rays so the existence of both the transitions is assumed and a combined intensity is quoted. Table 4 compares the relative intensities obtained in this work to those of other experimenters. All three of the other experimenters used beta-ray spectrometers for their work.

Six gamma rays at energies 301, 492, 497, 531, 532, and 1432 keV were unobserved, making their existence uncertain. These transitions are shown dotted in the Ir 194 decay scheme.

A 589 keV gamma ray, previously unreported in Ir 194 decay was discovered. It was placed in the Ir 194 decay scheme between the 1512 and 923 keV energy levels by energy fit and because a transition of this energy occurs in Pt^{194} following Au^{194} decay (3). A gamma-gamma coincidence measurement could be performed in an attempt to verify this placement; however, since the 1512 keV level is populated only by the 532 keV transition and the only transition from the 923 level is at 301 keV (both of these gamma rays unobserved in this work, indicating low intensities), the attempt would probably not succeed. Since the 301 keV gamma ray next to the intense 294 keV gamma ray was not resolved, it is possible that the 925 keV gamma ray transition between the 1547 and 622 keV energy levels should also be placed in the decay scheme as a ground state transition from the 923 keV energy level.

Table 3. Comparison of Relative Intensities in Pt^{192} and Os^{192}.

$$\frac{100\ I_\gamma}{I\ 316}$$

Gamma Ray Energy (keV)	Johns and Nablo ref. 4	Baggerly et al ref. 5	Hultberg et al ref. 6	Bergvall ref. 9	Present Work
136	3.4	0.19			
173	1.04				
201	1.04	0.46			4.73 ± 0.07
206	4.5	3.9			
282	1.3	0.6			0.33 ± 0.02
283					
295	33.8	36	39 ± 2	34.5	31.9 ± 0.3
308	36.4	35	46 ± 2	38.0	35.5 ± 0.3
316	100	100	100 ± 3	100	100.0 ± 0.8
374	0.65	1.9			0.74 ± 0.02
417		1.6			0.91 ± 0.02
438	0.65				
468	74	64	89 ± 8	60.2	57.7 ± 0.1
484	6.8	3.9			4.25 ± 0.02
489					
588	8.3	7.1	6.6 ± 0.7	4.2	5.34 ± 0.03
604	13	14	13.0 ± 0.8	9.5	9.70 ± 0.04
612	10	8.4	8.0 ± 0.6	7.5	5.84 ± 0.03
885	1.2	0.5			0.33 ± 0.01
1063	0.19	0.05			0.054 ± 0.004

Table 4. Comparison of Relative Intensities in Pt^{194}.

$$\frac{100\ I_\gamma}{I\ 1152}$$

Gamma Ray Energy (keV)	Johns and Nablo ref. 4	Kern and Bäckström ref. 7	Present Work
294	176	407 ± 69	563 ± 15
301		57.9 ± 13.8	
328	931	2052 ± 207	2447 ± 42
589			32.4 ± 1.7
622	58	52.8 ± 10.3	51.4 ± 1.2
645	214	169 ± 14.0	219.0 ± 0.8
Same	Vitman et al ref. 8	Same	Same
890	13 ± 3	6.6 ± 0.7	8.3 ± 1.1
925	6 ± 2	5.6 ± 0.7	3.4 ± 1.0
939	95 ± 5	93.1 ± 3.4	83.2 ± 1.9
1000	8.6 ± 1.4	5.2 ± 1.0	10.1 ± 0.4
1049	5.4 ± 1.0	4.6 ± 0.3	4.0 ± 0.3
1104	4.4 ± 0.8	3.8 ± 0.3	4.9 ± 0.4
1152	100 ± 0.0	100 ± 3	100.0 ± 0.7
1176	13 ± 4	10.3 ± 1.7	11.8 ± 0.8
1184	48 ± 3	49.7 ± 3.4	48.3 ± 1.3
1219	9 ± 1.3	10.9 ± 0.9	8.1 ± 0.4
1294	8.1 ± 1.6	8.3 ± 0.9	7.2 ± 0.4

Table 4 (cont.). Comparison of Relative Intensities in Pt^{194}.

$$\frac{100\ I_\gamma}{I\ 1152}$$

Gamma Ray Energy (keV)	Vitman et al	Kern and Bäckström	Present Work
1343	7.1 ± 0.9	3.4 ± 0.5	5.7 ± 0.3
1432		0.70 ± 0.35	
1470	31.2 ± 1.6	29.3 ± 1.7	30.3 ± 0.4
1489	3.4 ± 0.9	2.6 ± 0.5	2.5 ± 0.2
1492			
1512	6.3 ± 1.0	5.7 ± 0.9	4.8 ± 0.3
1569	3.6 ± 0.6		2.2 ± 0.2
1622	10.4 ± 1.2	15.2 ± 1.0	8.4 ± 0.2
1671	0.8 ± 0.3	2.1 ± 0.3	1.5 ± 0.1
1786	2.1 ± 0.8	1.6 ± 0.5	1.2 ± 0.1
1798		3.8 ± 0.7	1.4 ± 0.1
1806	7.3 ± 1.0	9.7 ± 1.4	4.9 ± 0.2
1830		0.55 ± 0.17	0.33 ± 0.06
1925	0.37 ± 0.11	0.76 ± 0.30	0.28 ± 0.06
2044	1.0 ± 0.2	1.41 ± 0.07	0.80 ± 0.07
2114	0.5 ± 0.2	0.59 ± 0.07	0.40 ± 0.05

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RELATIVE INTENSITIES OF GAMMA RAYS IN IR 192 AND IR 194 DECAY

by

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The radioactive decays of Ir 192 and Ir 194 have been studied extensively in the past and relative intensities of gamma rays in those decay processes determined using NaI scintillation detectors, beta-ray spectrometers, and curved crystal diffraction spectrometers; however, they have not been examined with semiconductor detectors. For this reason, it was desirable to examine the two decay processes and determine relative intensities of gamma rays resulting from the decay of Ir 192 and Ir 194.

A lithium-drifted germanium detector, cooled to liquid nitrogen temperature, was used to study the decay of Ir 194 which was produced by irradiating stable irridium metal in the Triga Mark II reactor at Kansas State University and Ir 192 which was purchased commercially having a purity greater than 98%. The Technical Measurement Corporations 4096 multiparameter pulse analyzer system with compatible amplifiers was used to accumulate data which when corrected for peak-to-total value and efficiency yielded relative intensities.

The relative intensities of the gamma rays in Pt^{192} and Os^{192} at energies 201 unresolved from 206, 282 unresolved from 283, 295, 308, 316, 374, 417, 468, 484 unresolved from 489, 588, 604, 612, 885, and 1063 keV were determined to be 4.73, 0.33, 31.9, 35.5, 100, 0.74, 0.91, 57.7, 4.25, 5.34, 9.70, 5.84, 0.33, and 0.054.

The relative intensities of the gamma rays in Pt^{194} at energies 294, 328, 589, 622, 645, 890, 925, 939, 1000, 1049, 1104, 1152, 1176, 1184, 1219, 1294, 1343, 1470, 1489 unresolved from 1492, 1512, 1569, 1622, 1671, 1786, 1798, 1806, 1830, 1925, 2044, and

2114 keV were determined to be 563, 2447, 32.4, 51.4, 219, 8.3 3.4, 83.2, 10.1, 4.0, 4.9, 100, 11.8, 48.3, 8.1, 7.2, 5.7, 30.3, 2.5, 4.8, 2.2, 8.4, 1.5, 1.2, 1.4, 4.9, 0.33, 0.28, 0.80, and 0.40.

A previously unreported gamma ray of energy 589 keV was discovered in the Ir 194 decay and placed in the decay scheme between the 1512 and 923 keV energy levels.